Effect of Bubbles on Optical Backscatter Sensors

Jack A. Puleo
Center for Applied Coastal Research
Department of Civil and Environmental Engineering
University of Delaware
Newark, DE 19716
Phone: (302) 831-2440; fax (302) 831-1228; email: jpuleo@coastal.udel.edu

Award Number: N00014-05-1-0081

LONG-TERM GOALS

The long term goals are to provide the Navy and scientific community with accurate methods for measuring and predicting sediment transport in the nearshore environment.

OBJECTIVES

Measuring sediment suspension and transport in the surf and swash zones on beaches is a daunting task, not only because of the harsh conditions, but also due to the presence of bubbles. There are typically two methods for addressing sediment transport measurements: acoustic and optic. It is known that acoustic backscatter instruments have particular difficulty in bubbly environments (Vincent et al., 1991) such as near the breakpoint and in the swash zone, but may experience much less artificial signal amplification other regions of the surf zone where little bubble entrainment reaches the bed. More debate in the scientific literature exists as to the effect of bubbles on optical backscatter sensors (OBS's). Several studies have briefly mentioned the effect of bubbles on optical backscatter sensors (e.g. D&A Instruments, 1991; Black and Rosenberg, 1994; Butt and Russell, 1999; Downing et al., 1981; Greenwood et al., 1990; Puleo et al., 2000; Smith and Mocke, 2002; Sternberg et al., 1984), but no exhaustive study has been completed.

Using a suite of air bubble generators, a laboratory study is undertaken to:

1) Quantify the effect on OBS's of bubble sizes and densities in the ranges observed in previously published surf zone studies,

2) Quantify the effect on OBS's of bubbles for sizes and/or densities outside these ranges to potentially account for conditions that may be encountered in the swash zone (no study of bubble size or density has, to my knowledge, been undertaken in the swash zone),

3) Determine if the effect of bubbles is mitigated when sediment is suspended in the region of the sensor.

APPROACH

The approach involves the construction of a laboratory bubble generator test tank (BGTT; Figure 1) that was fabricated by Rex Johnson as part of an earlier ONR funded project (PI: Puleo).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Effect of Bubbles on Optical Backscatter Sensors**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Delaware,Department of Civil and Environmental Engineering,Center for Applied Coastal Research,Newark,DE,19716**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Figure 1: Bubble Generator Test Tank (BGTT).
Picture shows optical backscatter sensor (black sensor to the right) and bilge pumps used to stir the water.

The tank is outfitted with numerous bilge pumps to stir water. Bubbles are generated using several different bubble generators that produce bubbles within and outside the ranges found in previous surf zone studies. In addition, the volume flow rates are varied to alter the bubble concentration in the tank. A single optical backscatter sensor is placed at one end of the tank with the output recorded as voltage. Values are collected for a variety of test conditions including 3 water types (fresh, salt, synthetic salt), varying mud and sand concentrations, varying bubble concentrations and the various bubble generators. Comparisons are then made between clear water runs and those with and without bubbles and sediment to determine the effect bubbles have on optical baskscatter sensors.

WORK COMPLETED

In December, 2003, Puleo traveled to the University of Washington for the two week lab study. During this time, Puleo and Rex Johnson performed over 1200 one-minute runs (including replicates) by varying all the parameters of interest (water type, bubble generator, bubble concentration, sediment type and sediment concentration). Subsequent work related to this project involved data quality control, data reduction, developing analysis algorithms in Matlab and developing video-based algorithms for determining bubbles size (Table 1).

Table1. Bubble sizes used.
Bubble generators, pore size, flow rates and bubbles sizes for the given flow rates for fresh and salt water in un-stirred conditions showing sizes spanning 0.25 to almost 5 mm.

	Nominal pore size (mm)	Air Flow rates (liters/min)		Bubble Size (mean±std) mm	
		Fresh	Salt	Fresh	Salt
Point4 ceramic air stone	0.0018	<0.05	<0.05	0.25 ± 0.06	0.29 ± 0.13
Sintered tube (fine)	0.01	1	0.1	0.41 ± 0.20	0.17 ± 0.04
Sintered tube (coarse)	0.104	1	0.7	1.93 ± 0.47	1.49 ± 0.50
Aquarium air stone	Unknown	1	1	3.17 ± 0.66	1.87 ± 0.51
PVC pipe	0.53	3.3	2	4.70 ± 1.37	4.25 ± 1.11

RESULTS

The results from this work are geared towards quantifying the effect of bubbles on optical backscatter sensors under a variety of conditions. Figure 2 shows the effect of bubbles generated by the fine sintered tube (one of five bubblers tested) in the presence of sand and mud, obtained by holding the bubbler location a constant 10 cm from the OBS, but stirring the water with the bilge pumps. Individual dots represent the mean voltage from the replicate runs for the various sand and mud concentrations. The colors represent the various flow rates; black being no flow, blue being 1.0 l min^{-1}, magenta being 2.0 l min^{-1} and green being 5.0 l min^{-1}. Solid lines are least squares fits to aid in visual observation and yield the calibration slope, $s = \frac{gl^{-1}}{V}$. There is an increase in OBS output with an increase in sediment concentration and an increase in volume flow rate (bubble concentration). In the case of fresh water, little variation is seen between the bubble-injected and bubble-free cases potentially due to a lack of bubble persistence. The largest differences between background bubble-free conditions and those with bubbles are seen for the synthetic salt water cases, where the OBS output voltage can nearly double. In the presence of bubbles, the calibration curves have a smaller slope because the bubbles represent additional scatterers that are not indicative of the sediment concentration. An easy means to visualize this effect is through Figure 2 for the synthetic salt water case. Roughly 5 volts corresponds to a sand concentration of 100 g l^{-1} with no bubbles (black dot) whereas roughly 5 volts corresponds to only 50 g l^{-1} in the presence of bubbles (green dot). Using the black (no-bubble) calibration curve, as one would typically use for field data, the 5 volt measurement would incorrectly suggest a concentration of 100 g l^{-1} rather than the 50 g l^{-1} measured in the bubbly environment.

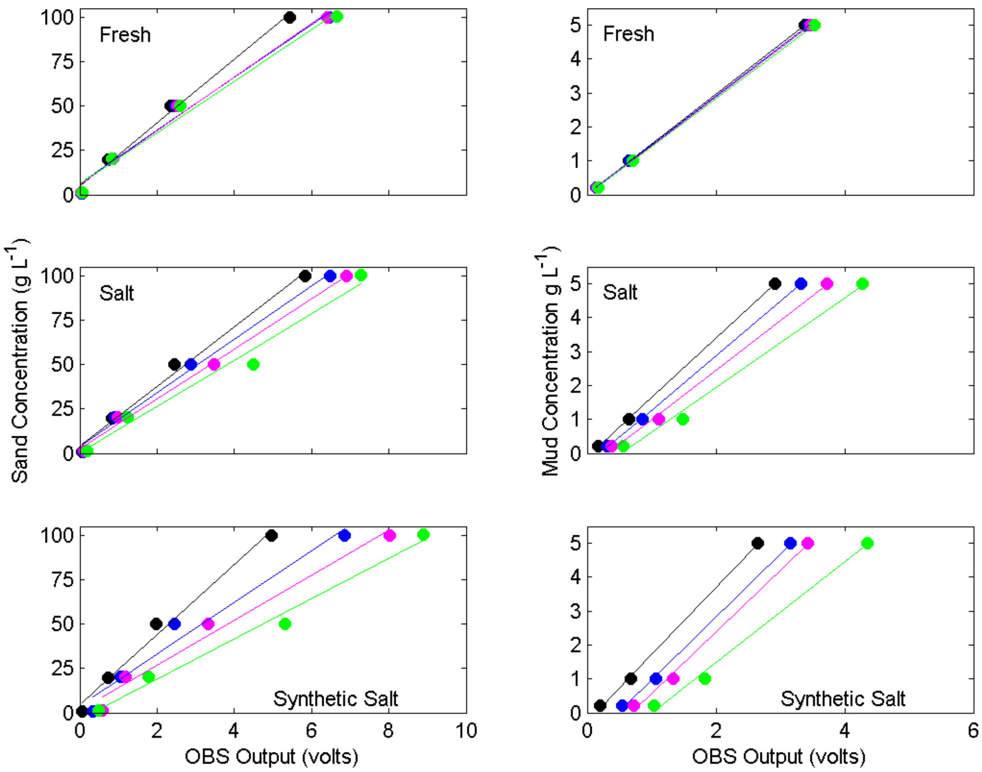

Figure 2. Mean OBS output voltage.
OBS response for the fine sintered tube bubble generator for the three water types and various flow rates and sediment concentrations. Black: background values with no bubble generation, blue: 1.0 l min^{-1} flow rate, magenta: 2.0 l min^{-1} flow rate, green: 5.0 l min^{-1} flow rate. Solid line is least squares fit calibration curve. Voltage increases with increasing bubble concentration.

Because Figure 2 contains a large quantity of information, it is necessary to develop a simple means to observe the data from all 5 bubblers simultaneously rather than reproducing additional figures similar to Figure 2. To do so, we chose the calibration slope as the parameter of interest and investigated the ratio of the calibration slope, s, to the calibration slope of the background bubble free condition, s_b as $R= s/s_b$ (Figure 3). The ratio determines the OBS output voltage that would need to be measured in a bubbly environment to yield a corresponding sediment concentration based on the background calibration curves. As an example, using the fine sintered tube in synthetic salt water (Figure 2 and 3 panel B_s), R is slightly larger than 0.5 suggesting that the OBS output in a bubbly environment would only have to be approximately half that measured in a bubble-free environment to infer a sediment concentration based on the bubble-free calibration curve. Panels on the left of Figure 3 indicate the sand tests (subscript s), and those on the right, the mud tests (subscript m). Moving down the figure, the panels represent the following bubblers: Point4, fine sintered, coarse sintered, Aquarium Air Stone and PVC respectively. Each bar represents R for the flow rate described in the caption with F, S and SS representing fresh, salt and synthetic salt water respectively. In nearly all the fresh water cases, regardless of bubbler or flow rate, R ranges from about 0.75 to 1 implying that, in these cases, bubbles cause up to a 25 % increase in OBS output voltage.

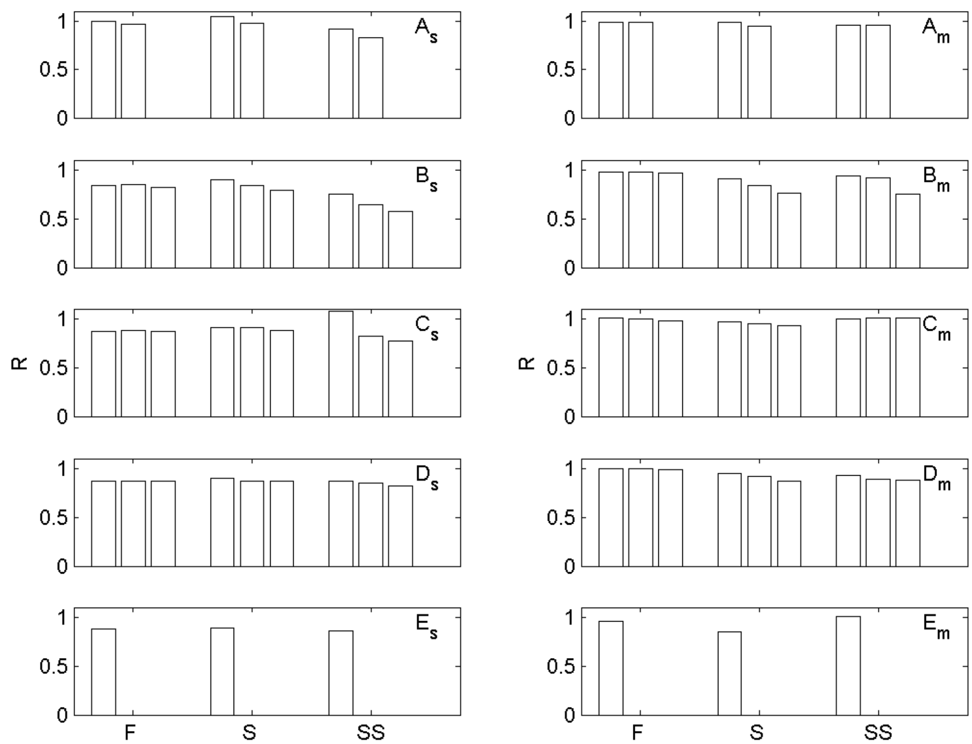

Figure 3. Calibration slope comparison.
The calibration slope ratio $R=s/s_b$ for the five bubblers, various flow rates, sand (left panels; subscript s) and mud (right panels; subscript m), and water types (F=fresh, S=salt, SS=Synthetic Salt). A_s,A_m) Point4 with flow rates of <0.05 l min^{-1} and 0.1 l min^{-1} for each water type. B_s,B_m) Fine sintered tube with flow rates of 1.0 l min^{-1}, 2.0 l min^{-1} and 5.0 l min^{-1} for each water type. C_s,C_m) Coarse sintered tube with flow rates of 1.0 l min^{-1}, 2.0 l min^{-1} and 5.0 l min^{-1} for each water type. D_s,D_m) Aquarium air stone with flow rates of 1.0 l min^{-1}, 2.0 l min^{-1} and 5.0 l min^{-1} for each water type. E_s,E_m) PVC pipe with a flow rate of 3.3 l min^{-1} for each water type.

Expressed another way, in a bubbly freshwater environment, 25 % less sediment needs to be present to yield the same OBS output voltage as in a bubble-free environment. In general, the adverse bubble effect tends to increase with bubble concentration as evidenced by the decrease in *R* as a function of flow rate for a given water type. In addition, *R* tends to decrease as the salinity increases (from fresh to salt to synthetic salt). Thus, in salty environments, where bubbles tend to be smaller, the false increase in OBS concentration due to bubbles may be larger than the 25 % found in fresh water. In the case of mud, the effect of bubbles tend to be small (< 5 %) due to poor water clarity except in the cases using salt and synthetic salt water where the bubbles are numerous and small (fine sintered tube).

IMPACT

The results from this study suggest that care must be taken in trying to infer sediment transport from optical backscatter sensors placed in the nearshore. Errors in the sediment concentration owing to the presence of bubbles could lead to large errors in bathymetric predictions.

REFERENCES

Black, K.P. and Rosenberg, M.A., 1994. Suspended sand measurements in a turbulent environment: field comparison of optical and pump sampling techniques. Coastal Engineering, 24: 137-150.

Butt, T. and Russell, P., 1999. Suspended sediment transport mechanisms in high-energy swash. Marine Geology, 161(2-4): 361-375.

D&A Instruments, 1991. Instruction Manual, OBS-1 & 3. D & A Instrument Company, pp. 41.

Downing, J.P., Sternberg, R.W. and Lister, C.R.B., 1981. New instrumentation for the investigation of sediment suspension processes in the shallow marine environment. Marine Geology, 42: 19-34.

Greenwood, B., Osborne, P.D., Bowen, A.J., Hazen, D.G. and Hay, A.E., 1990. C-COAST: The Canadian Coastal Transport Programme - Suspended sediment transport under waves and currents, Canadian Coastal Conference. ACOS National Research Council, Kingston, Ontario, pp. 319-336.

Puleo, J.A., Beach, R.A., Holman, R.A. and Allen, J.S., 2000. Swash zone sediment suspension and transport and the importance of bore-generated turbulence. Journal of Geophysical Research, 105(C7): 17021-17044.

Smith, C.G. and Mocke, G.P., 2002. Interaction between breaking/broken waves and infragravity-scale phenomena to control sediment suspension transport in the surf zone. Marine Geology, 187: 329-345.

Sternberg, R.W., Shi, N.C. and Downing, J.P., 1984. Field investigations of suspended sediment transport in the nearshore zone, 19th International Conference on Coastal Engineering. American Society of Civil Engineers, Houston, Texas, pp. 1782-1798.

Vincent, C.E., Hanes, D.M. and Bowen, A.J., 1991. Acoustic measurements of suspended sand on the shoreface and the control of concentration by bed roughness. Marine Geology, 96: 1-18.

PUBLICATIONS

Puleo, J.A., Kooney, T.N. and Johnson, R.V., II, 2004. Laboratory generation of air bubble curtains of various size distributions. Review of Scientific Instrumentation, 75(11): 4558-4563 [Published, refereed].

Puleo, J.A., Johnson, R.V., Butt, T., Kooney, T.N. and Holland, K.T. The Effect of Air Bubbles on Optical Backscatter Sensors. Marine Geology [In Review, refereed].

Puleo, J.A., R.V. Johnson and K.T. Holland. 2004. Laboratory investigation of the effect of bubbles on optical backscatter sensors. *Eos. Trans*. AGU, 84 (52), Ocean Sci. Meet. Suppl., Abstract OS52B-10.

Puleo, J.A. and R. Johnson. 2004. The effect of bubbles on optical backscatter sensors. *Eos Trans*. AGU, 85 (47), Fall Meet. Suppl., Abstract OS21B-1219.